

Chemically Contaminated Aquatic Food Resources and Human Cancer Risk: Retrospective*

It was the original intent of the Steering Committee to include a fourth session, to be attended by all conferees and devoted to identifying the most urgent research needs pertinent to the subject of the conference. Time limitations unfortunately precluded this possibility. The Committee therefore invited the conferees to submit, subsequent to the meeting, their comments and suggestions regarding future research needs. These comments and others brought forward in the course of discussions at the meeting were reviewed at several post-meeting reconvenings of the Committee. Below are presented, in summary form, what we consider to be the most critical knowns and unknowns identified and the types of information most obviously needed if useful risk determinations are to be accomplished through future investigations.

Knowns and Unknowns

Pathological-Geographical Aspects

Data accumulated from surveys over the past 25 years provide ample evidence that high prevalences of hepatic and epidermal neoplasms of fishes are generally associated with aquatic habitats that are extensively contaminated by products of urbanized-industrialized human populations and certain species that, for the most part, have bottom-feeding lifestyles. In Table 1 are listed species, geographic locations, and neoplastic types representing the basis for this statement.

Some species of fish, particularly widely migratory ones such as bluefish, striped bass, and coho salmon, have been found to have readily detectable and sometimes greatly elevated concentrations of PCBs in their edible tissues, yet these same species have not yet been found to have high prevalences of hepatic or other neoplasms. Several points deserve note in relation to this observation: *a)* Under experimental conditions, PCBs administered simultaneously with or prior to exposure to a carcinogen can have either an enhancing or an inhibitory effect on liver tumor induction, depending on the carcinogen used. *b)* Levels of PAHs and chlorinated hydrocarbon pesticides have not regularly been quantified in the same fish found to have high PCB levels. *c)* PCBs have generally been found to be weak cancer

inducers. *d)* In the Great Lakes, where PCB levels are high in coho salmon, severe thyroid hyperplasia has been found in that species. From results of laboratory experiments, it is evident that these compounds can block thyroid hormone binding to cell receptors and thus can have widespread effects on cell metabolism. In any case, the reasons for absence of high prevalences of liver neoplasms in pelagic predatory species currently are unknown. It is known that particular pelagic species can develop neoplasms after exposure to particular carcinogens under laboratory conditions, but this is of no direct relevance to the matter of cancer risk to consumers of the fish.

The gross, microscopic, and ultrastructural features of the neoplasms do not permit identification of causal agents or combinations of agents. At present, the specific chemical cause or combination of causes of any of the fish neoplasms, in whatever tissue site or at whatever geographic location, is unknown. Because the array of chemical contaminants is different at different geographical locations, it seems probable that the causal agents also vary from location to location and from species to species. It cannot be ruled out, however, that factors in common exist, as well as factors that vary.

The terms "epizootic" and "enzootic" have been variously applied to neoplastic types found at high prevalences in focal habitats. It is not clear which term, if either, is accurate, as time-course information that might reveal trends over long time periods is lacking. There is now a paucity of clean habitats supporting known indicator species. However, it is clear that where clean habitats for these species do exist, hepatic and epidermal neoplasms occur only at extremely low prevalences, or not at all.

Because bottom-feeding fishes appear to be at higher risk than strictly pelagic fishes, it has been postulated that exposure of bottom-feeders occurs through ingestion of food animals living within or in contact with sediments containing carcinogens/promoters. The evidence supporting this postulate is that *a)* detritus-feeding and filter-feeding invertebrates, which represent the food supply of bottom-feeding fish, live in or upon contaminated sediments and contain elevated levels of PAHs and chlorinated pesticides; *b)* extracts of contaminated sediments, in a small number of laboratory trials, have induced hepatic and epidermal neoplasms when applied topically or internally, respectively, to one indicator species (brown bullhead).

Neoplasms also occur in several species of invertebrate aquatic animals consumed by man, and at a variety of geographic

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Table 1. Neoplasms of hepatic and orocutaneous origin in fishes from xenobiotically contaminated sites.

Species (common name)	Neoplastic type	Location
White sucker	Cholangiocytic	Deep Creek Lake, Maryland
Slimy sculpin	Cholangiocytic and hepatocytic	Western Lake Ontario and tributaries
White sucker		
Brown bullhead		
White sucker	Epidermal papilloma	Eastern Lake Erie and tributaries, Buffalo, New York
White sucker	Cholangiocytic and epidermal papilloma	Trent River, Bay of Quinte, Ontario, Canada
Slimy sculpin	Cholangiocytic	Ganarasta River, Port Hope
White sucker		
White sucker	Epidermal papilloma	Ontario, Canada, Lake Ontario
Slimy sculpin	Cholangiocytic	Southern Lake Ontario, Olcott, New York
Cunner	Odontogenic	Sakonnet River, Portsmouth, Rhode Island
White croaker	Epidermal papilloma and hepatocytic	Southern California coast
English sole	Cholangiocytic and hepatocytic	Puget Sound, Washington
Rock sole		
Pacific staghorn sculpin		
English sole	Hepatocytic	Vancouver Harbor, British Columbia
Atlantic tomcod	Hepatocytic	Hudson River, New York
Winter flounder	Cholangiocytic and hepatocytic	Quincy Bay and Boston Harbor, Massachusetts
Winter flounder	Cholangiocytic	New Bedford Harbor, Massachusetts
Winter flounder	Hepatocytic	Central Long Island Sound (dumpsite of Black Rock Harbor, dredge soils)
Winter flounder	Cholangiocytic and hepatocytic	Black Rock Harbor, Bridgeport, Connecticut
Brown bullhead	Epidermal papilloma	Delaware and Schuylkill Rivers, New Jersey and Pennsylvania
Brown bullhead	Hepatocytic	Fox River, Illinois
Brown bullhead	Cholangiocytic	Black River, Ohio
Brown bullhead	Cholangiocytic	Cuyahoga River, Ohio
	Hepatocytic	
	Epidermal papilloma	
	Squamous carcinoma	
Brown bullhead	Epidermal papilloma	Inner Harbor of Presque Isle Bay, Lake Erie, Pennsylvania
Brown bullhead	Epidermal papilloma	Port Rowan, Ontario, Lake Erie
Brown bullhead	Hepatocytic	Munuscong River, Michigan
Brown bullhead	Epidermal papilloma and squamous carcinoma	Lakes in Polk County, Florida
Yellow bullhead		
Brown bullhead	Cholangiocytic	Epsy Bog, Pennsylvania
Brown bullhead	Cholangiocytic	Silver Stream Reservoir, Newburgh, New York
	Hepatocytic	
Brown bullhead	Cholangiocytic	Lake Ontoloni, Reading, Pennsylvania
Black bullhead	Epidermal papilloma	Sewage treatment pond, Tuskagee, Alabama
Sauger	Hepatocytic	Torch Lake, Houghton County, Michigan
Walleye		
White perch	Cholangiocytic and hepatocytic	Chesapeake Bay, Delaware Bay, Pennsylvania, Maryland, New Jersey
Bowfin	Cholangiocytic	Lower Detroit River, Michigan, and Windsor, Ontario
Oyster toadfish	Hepatocytic	Elizabeth River, Southeast Virginia

*Pathological data compiled from Harshbarger and Clark (7).

locations. In crustaceans, such as shrimp, crabs, lobsters, and crayfish, neoplasms are so rare, given our present state of knowledge, that they show little promise of being useful indicators of environmental carcinogens. However, in specific instances, high prevalences of gonadal neoplasms in softshell clams have been temporally and geographically associated with several Maine habitats contaminated by chlorinated herbicides, but a causal relationship has not been clearly established.

In the Chesapeake Bay, leukemialike neoplasms of softshell clams have been found at decimatingly high prevalences. Although in that geographic area there is correlation between neoplastic prevalence and the presence of low levels of chlordane in the clam tissues, there is epizootiological and experimental evidence that the clam neoplasm is transmissible, either through cell transplantation or by a cell-free agent. In general, the question as to whether molluscan neoplasms are useful as indicators of environmental chemical carcinogens remains moot. This does not exclude the possibility that molluscs (and crustaceans as well) may be more important as conveyors of carcinogens to human consumers than fish, which are more efficient in metabolizing and excreting certain carcinogens, e.g., PAHs.

Relating to the topic of this conference, the question most often asked of scientists and public health professionals by consumers is: "Is it safe to eat fish with tumors?" Aside from the problem of defining the intended meaning of "safe," this question is complex in that it requires consideration of the scientifically conceivable mechanisms that might operate to increase cancer risk in consumers of tumor-bearing fish or shellfish. These mechanisms are: via transplantation of viable tumor cells from the animals to the consumer; via infection of the consumer by an oncogenic microorganism such as a virus, bacterium, or even a protozoan or metazoan parasite that is causal of the tumor in the fish or shellfish; via a more subtle mechanism such as transfection of the consumer's cells by mutated or nonmutated oncogenes or protooncogenes in the genetic materials of the consumed tissues; via ingestion of carcinogens or procarcinogenic chemicals (which could include radionuclides) present in the animal at the time of consumption, and which, with or without possible biochemical transformations during cooking or other preparation for eating, are carcinogenic for human beings.

Without elaborating in detail, there was complete agreement among the conferees and the Steering Committee that, on the basis of all that is known in cancer biology, the first three of the above conceivable mechanisms do not deserve serious consideration. The focus of the conference therefore centered upon analytical chemistry aspects, biochemical linkages, and risk assessments, as summarized in the following sections.

Biogeochemical Cycles and Distribution of Chemicals of Concern

The major portions of the biogeochemical cycles of known or suspected procarcinogens such as PAHs in coastal ecosystems have been elucidated, at least semiquantitatively, by a combination of laboratory experiments, field observations, and carefully controlled experiments in large scale, e.g., 21,000 L mesocosms. Sources of PAHs attributable to modern industrial society are chronic oil releases from routine shipping activities; industrial and municipal sewage treatment plant operations; road

runoff; creosote from pilings; exhaust from small boat inboard and outboard engines; oil spills, and offshore oil well operations. In addition, there has always been an input of PAHs to coastal ecosystems as a result of PAHs produced in grass and forest fires and transported by atmospheric processes and/or fluvial processes to coastal areas, as well as oil seeps in selected coastal areas, and small amounts due to early transformations of biological precursors to aromatic hydrocarbons, e.g., transformation of cholesterol deposited in sediments to monoaromatic steroidal hydrocarbons.

The analyses of surface sediments and sediment cores show that coastal areas in a few locations around the United States (northeastern U.S. estuaries, Puget Sound waters, Great Lakes) have been receiving as much as one to two orders of magnitude higher inputs of chemicals such as PAHs, PCBs, and chlorinated pesticides in recent decades. The cores contain historical record of increased inputs by a modern industrial society. The relative distributions of the PAHs clearly indicate increased inputs from incomplete combustion of fossil fuels as compared to inputs from chronic oil spills. There is some evidence in the historical record of increased inputs from chronic oil releases.

There are higher concentrations of these chemicals in sediments from urban harbors and near industrialized areas as compared to concentrations in more remote, pristine areas. Compounds such as PAHs, PCBs and chlorinated pesticides reach high concentrations in the sediments due to their hydrophobic nature, the resultant sorption on particulate matter, and deposition of the particulate matter to sediments. In many respects this can be thought of as a removal process or a sink. However, it is a leaky sink. There is evidence from field and laboratory studies that these chemicals are released slowly back into the water column and pore waters of sediments and can be taken up from both the water and sediments by aquatic animals living in or on the sediment. Thus, even if inputs of these chemicals to aquatic ecosystems are reduced or eliminated, the sediments will be a source for uptake in the food web and transfer back to humans via food for many years in the future, perhaps for decades.

There have been modern surveys of concentrations of chlorinated pesticides, PCBs, and PAHs in selected aquatic organisms, especially shellfish. The U.S. EPA Mussel Watch program sampled approximately 100 coastal locations around the United States once per year in 1976, 1977, and 1978 for concentrations of chemicals of environmental concern in coastal waters. This prototype program has been followed by a more thorough monitoring program, the Status and Trends Program operated by NOAA. Both programs analyzed for a suite of chemicals in mussel and oyster tissue. The Status and Trends Program also analyzes for the same suite of chemicals in fish tissue samples and surface sediments. Numerous individual studies of selected coastal areas also have been published by many scientists. Collectively, data provide a composite picture of chemical contamination in various species of aquatic organisms in coastal areas.

The data document that sedentary aquatic species, and many mobile species, sampled near urban harbor or industrialized areas have elevated concentrations, by factors of one to two orders of magnitude or more, of the chemicals of concern when compared to samples obtained from more remote, less industrialized and less populated locations. This parallels the findings for sediments.

There are some differences in distributions of compounds in tissues as compared to sediments. For example, sediments in urban harbor areas tend to have a signature of PAH composition dominated by pyrogenic sources, while organisms such as shellfish tend to have a PAH composition showing more petroleum input. This has been attributed to the greater bioavailability of the petroleum PAHs compared to the pyrogenic PAH. In addition, metabolic transformation of these compounds can alter the distribution and concentration of PAHs in tissues of fish and some invertebrates. A change in PCB mixture composition and pesticide mixtures, found in comparing data on sediments and bivalves with data on fish and crustacea, can also be attributed to metabolic transformations.

Some important points need to be emphasized. Analyses reveal hundreds and sometimes thousands of unknown compounds present in relatively high concentrations when compared to samples from remote areas. Relatively few compounds among the vast array of organic chemicals that are products or byproducts of industrial processes and of chemical or biochemical transformation processes after release of compounds to the environment have been unequivocally identified in samples from coastal environments. Only a few may prove to be of environmental concern from a human health perspective, but which ones are they and how many are present? No more than 5 to 10 of the compounds for which we have reliable, well-calibrated data are known to be among the more potent carcinogens or procarcinogens. The vast array of xenobiotics and fossil fuel compounds present in many of the tissue samples and in the sediments raises the issue of how to provide reasonably accurate risk assessment for complex mixtures of procarcinogens and promoters.

Numerical models of biogeochemical cycles of compounds that take into account inputs, pharmacokinetics of uptake and disposition in tissues, and metabolism are now available in rudimentary form. These might be connected to human health risk assessment/dose-response-type models to provide a first-order, overall risk assessment model that goes from source through the ecosystem and back to consumers of fisheries products. Testing and refinement of these models is a high priority. There has been progress in the past few years in improving such models.

The fact that many species of aquatic organisms have the capacity to transform compounds of environmental concern makes it difficult to correlate concentrations of parent compounds with known prevalences of cancers of various types in fish. But first-order correlations have been noted in a few cases. The general picture that emerges is one of higher prevalences of cancers in species located or sampled in areas where other parts of the ecosystem, e.g., sediments, have high concentrations of known or suspected carcinogens and other compounds of concern to human health.

Biochemical Linkages

PAHs that are known carcinogens have been identified in the surrounding environments and in the tissues of fish and shellfish at many geographic locales. Other compounds that could act as tumor promoters are also present in these environments and/or tissues. Fish metabolize (break down) some PAHs including some known carcinogens such as benzo(a)pyrene very efficiently.

Therefore, the amounts of such materials detected in these animals do not indicate the degree of prior chronic exposure, which has cumulative effects with respect to carcinogenesis. This metabolism aids elimination but some products of metabolism are themselves highly carcinogenic.

Less is known about the metabolism of many chlorinated hydrocarbons, including PCBs, by fish. However, data presently indicate that some chlorobiphenyl congeners in industrial PCB formulations are much more slowly broken down by fish than are PAHs and that levels of some chlorobiphenyl congeners in tissues reflect the levels in the environment more closely than do hydrocarbons.

The enzymes (cytochromes P-450) that transform or break down PAHs are induced (increased) in fish by PAHs and PCBs. High levels of these enzymes in fish reflect exposure to these compounds and provide a useful biomarker for such exposure. The induction of transformation enzymes can enhance the rate of elimination and the rate of toxic or carcinogenic product formation.

Shellfish have very little capacity for metabolism of hydrocarbons or PCBs. Therefore, shellfish accumulate both types of compounds to levels higher than those appearing in fish from the same environments. This is particularly true for molluscan species such as clams, oysters, and mussels. There is little evidence for significant induction of hydrocarbon transformation rates in these species. Although fish do not accumulate high levels of potent PAH compounds because of metabolism, some products of this metabolism can be detected. These products can include some which accumulate in mobile form and which may be more available to consumers. Other products of metabolism are bound covalently to DNA, RNA, or protein. The availability of such bound products for uptake by consumers is not known.

The binding of some metabolites to DNA contributes to mutations and presumably to the development of disease, including neoplasms, in fish. The processes involved in initiating such diseases by chemicals appear to be the same in fishes and in humans. The lower rates of compound transformation and different metabolic processes in shellfish could contribute to the accumulation of parent compounds in shellfish and to the generally lower prevalences of neoplastic disease in many shellfish. Although fish might accumulate metabolites of procarcinogens and shellfish do accumulate the parent compounds, the relative importance of these to a consumer is not known. The accumulation of direct-acting carcinogens and promoters is also poorly known. Therefore, we cannot yet predict whether fish or shellfish are more likely to be significant vectors of chemicals to consumers.

Risk Assessment

There are at present no epidemiological data that provide useful information on the risks to humans of eating fish from chemically contaminated waters. Existing studies on fish and shellfish in the diet do not reveal any consistent positive or negative associations except in the case of salted or pickled fish. The settings and quality of other epidemiological studies, involving some of the same contaminants found in fish residues, are sufficiently different to preclude their application to the problem of eating contaminated fish.

There is not adequate information on the extent of fish and

shellfish consumption by human populations. We do not know the distribution or magnitude of consumption in various segments of the population, nor can we determine with any certainty the source of commercially available fish and shellfish in a particular geographic area. There is also a very incomplete picture of the residues found in the edible portion of fish and shellfish. The spatial and temporal variations and the identity and species distribution of various residues are largely unknown.

Risk assessment, while imperfect as a method and with a great many inherent uncertainties, is still useful as a means to put boundaries on the problem and as a basis for the design of further studies. Existing risk assessments of the problem do not exonerate the consumption of fish and shellfish from contaminated waters as a public health problem. A currently intractable problem in mathematical risk assessments is our lack of fundamental knowledge of how to deal with synergisms, antagonisms, and combinations of these two phenomena in mixtures of carcinogens.

The obstacles to performing a chronic animal bioassay using contaminated fish or shellfish in the diet are formidable. Moreover, because of the doses involved the power of the method would be small unless the animals' diets were artificially augmented with proportionate concentrations of the multiple known contaminants. Further, the nature and extent of the contaminant mixtures vary and are poorly characterized. In support of chronic feeding bioassays are two arguments: They offer the only practical approach to deal with the mixtures of contaminants that prevail in most aquatic animals from contaminated environments, and they provide the only method which accommodates the possibility that the identified carcinogens do not include one or more that actually caused the enzootic tumors.

A variety of short-term tests using residue mixtures may be helpful as a step toward a decision point on whether or not to undertake bioassays in mammalian species.

What Remains To Be Done

This conference was convened to examine what is known and what is not yet known about the public health implications of the fact that some feral fish and shellfish populations are experiencing enzootics of neoplasms, a phenomenon hypothesized by some to be related to xenobiotic contamination of many aquatic habitats. In the course of 2 days, a great deal of information was presented, and for the first time those most knowledgeable about the problem, so far as it affects fish and shellfish, shared information with those whose interest is primarily the health of human populations. The opinions expressed below are, except where noted, entirely those of the Steering Committee and do not necessarily represent the views of other participants or of the sponsoring organization, the National Institute of Environmental Health Sciences.

First, at the cost of being repetitious, but for the sake of emphasis, it is the opinion of the Committee that there was no evidence presented to indicate that the consumption of tumor-bearing fish or shellfish represents any human health risk if the sole consideration is the fact that the animals have tumors (neoplasms). As noted in the preceding sections, it is correct that tumor-bearing fish from contaminated habitats sometimes do have residues (usually small) of certain known carcinogens or their metabolites in their edible tissues, but this is by no means

uniformly so. Conversely, fish or shellfish with relatively high residues of carcinogens and/or promoters in their edible tissues more often than not bear no tumors. In short, there does not appear to be consistent correlation between level of residues of chemical contamination in fish and shellfish and the presence of tumors in those same individual animals.

On the other hand, there is a clear-cut correlation between increased prevalence of hepatic and epidermal tumors in certain species of fish and the presence of known carcinogens in the habitats of those fish. The converse is not consistently the case; i.e., there are many carcinogen-contaminated habitats where there are no known elevations in tumor prevalences in any species. The reasons may be that surveys may not have been adequately done; all of the resident species may be refractory to the carcinogens present, even though the carcinogens are taken up; the carcinogens may not be taken up by species that are otherwise capable of giving a tumorigenic response.

What do these observations tell us? The most important message is that it is in the interest of public health officials and consumers to replace earlier questions with the following more appropriate ones: *a*) In which specific habitats from which fish and/or shellfish are taken for human consumption (either commercially or for subsistence purposes) are there elevated levels of known carcinogens/promoters, especially in bottom sediments? *b*) What are the levels of carcinogens, procarcinogens, and promoters in the edible portions of each of the species harvested for human consumption from habitats identified as contaminated? (For widely migratory predatory fishes at the tops of food chains, such as salmon, tuna, swordfish, bluefish, striped bass, etc., the directly relevant questions are reduced to one: What are the levels of carcinogens, procarcinogens, and promoters in the edible flesh?) *c*) Are residents in the area adequately protected from other routes of exposure to these carcinogens, e.g., the sources of carcinogen production, or other uses of the water in addition to eating the fish?

Thus, at the start of the conference, a question of much concern was: To what extent do the several discoveries of enzootics of neoplasms represent sentinel events warning that an important segment of the human food supply might be compromised? At the conclusion of the conference, the answer to this question was evident: Enzootics, particularly of hepatic and epidermal neoplasms in fishes, have been of substantial value as indicators of environments containing carcinogens. They have been of much less value and are even unreliable as indicators of contamination of human food supplies. They are of value only to the extent that they identify the areas where other food animals as well as they themselves deserve analysis for carcinogen content in edible tissues. The indicator fish species may itself be relatively unimportant as a conveyor of carcinogens. An outstanding illustration of this comes from the recent Quincy Bay study, in which it was found that the edible tissues of nontumor-bearing lobsters and soft-shelled clams contained higher concentrations of PAHs than the edible tissue of tumor-bearing winter flounder from the same locale.

Because the questions of the past were different, the approaches to answering them were also different from approaches needed in the future. In the past, a pathological survey for tumor-bearing fish and shellfish was the first step. Usually a habitat was selected that was suspected to be contaminated, along with a

reference habitat believed to be uncontaminated. Then, if a tumor enzootic was found, chemical analysis of water column, bottom sediment, and tissues of tumor-bearing and non tumor-bearing individuals were carried out. In the future, with the foremost objective being the identification of food animals conveying carcinogens in their edible tissues, the appropriate successive steps would be:

- a) Identification of the geographic sites from which major quantities of fishes and shellfishes are harvested for human consumption. This would apply only to sites from which the particular food species do not migrate extensively.
- b) Chemical analyses for carcinogens in water column, suspended and sedimented particulates, and in the food supplies of the species consumed by humans.
- c) Biochemical analysis of mixed-function oxidases in liver, alimentary tract tissue, and kidney in the fishes. In molluscs and crustaceans, digestive organs and hepatopancreas, respectively, would be more appropriate for analyses for induced enzymes. These analyses would help determine whether the species in question is actually taking up carcinogens or closely related enzyme-inducing compounds from the environment.
- d) Chemical analyses of the edible tissues of the animals to be marketed for an array of known carcinogens, procarcinogens, and promoters developed from past experience. These analyses would determine whether the species in question is sequestering compounds in lipid reserves, gonads, and other tissues. Analysis of tissues as prepared for consumption is also important.
- e) Chemical, biochemical, and genetic studies to conclusively establish the causes of environmental neoplasms. Because some carcinogenic chemicals are not yet known and because all of the known ones could not be specifically tested for in the above routine, pathologists suggest that gross anatomic and histological examinations of adequate samples of the species be conducted in coordination with chemical studies. For example, if no carcinogens and no enzyme evidence of exposure to carcinogens were found, yet high prevalences of a tumor were found, it would be indicated to do a more thorough search for a carcinogen and to look for a viral oncogen, a radioactive agent, or an hereditary factor. Any of them, if found, would influence decisions relating to public health. Such a situation has been encountered, for example, in the enzootic lymphoma of northern pike, which is currently thought to be induced by a retrovirus, on the basis of laboratory evidence.

The first step of the procedure outlined above identifies a primary operational and informational need. Current activities of the FDA do not include identification of the geographic source of seafoods tested in its market basket testing program. NOAA, in its Status and Trends Program, analyzes for chemicals in mussels and oysters, but not in clams. This NOAA program is

surely the best source of information needed to identify the geographic habitats representing the main sources of marketed fish and shellfish. The services of the NOAA/NMFS are also a crucial element in the collection of marine animal samples. In many states the departments of sport and commercial fisheries can be useful both in the collection of animal samples and in the identification of major fish species caught and the geographic sites from which they are caught.

Without question, the most controversial session of the conference and the one in which the most diverse opinions were expressed was that devoted to risk assessment. This was also the session claiming the greatest gaps in basic knowledge and effective methodology, as outlined in the preceding section of this report. With this in mind, we nevertheless submit the following recommendations as a beginning toward answering the bottom-line question that this conference could not answer:

- a) Begin a systematic program to estimate the consumption of fish and shellfish in the human population. This might involve the addition of questions to one of the existing national surveys (e.g., NHANES) or be a special study designed expressly for this purpose. The object would be to identify populations at high risk either because of their sensitivity (e.g., the fetus) or their unusually high consumption (e.g., recreational or subsistence fishers).
- b) Begin a systematic program to determine the distribution, nature, and extent of residues in food fish and shellfish.
- c) Develop a program for short-term mutagenesis/carcinogenesis testing with contaminated fish and shellfish or residue extracts from contaminated fish and shellfish. Augment this with conventional animal bioassays on selected residues or residue mixtures where gaps exist in our current knowledge or the results of short-term tests warrant.
- d) Evaluate selected biologic markers of exposure or effects of exposure for potential use in epidemiologic studies.

Finally, the Steering Committee has made a determined effort to confine its statements and opinions to matters relating only to cancer risks. However, we would be remiss not to mention that many of the conferees thought that cancer risks (if known) from eating contaminated fish and shellfish would probably pale in comparison with other risks of such consumption. These include the risks of maldevelopment in children of mothers exposed to the same contaminated foods and the risk of losing a large part of our valuable aquatic food resources as a result of reproductive failures among the species exposed not only to environmental carcinogens, but also to many more acutely lethal toxicants. We leave these risk considerations to other conferences and other Steering Committees.

REFERENCES

1. Harshbarger, J. C., and Clark, J. B. Epizootiology of neoplasms in bony fish of North America. *Sci. Total Environ.* 94: 1-32 (1990).